

Bleed Roughness Mechanism

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Suction applied through wall bleed is expected to reduce boundary-layer thickness and lead to a profile that can resist separation. However, experiments with rows of suction holes or slots have shown that the benefits of suction are not realized under certain circumstances. Lee, Sloan and Paynter⁽¹⁾ attributed this to a "bleed roughness", and modeled the phenomena using a modified inner-length scale with convective lag for the eddy viscosity. Test information was required to determine the roughness values at each Mach number and bleed rate.

The present work used numerical calculation, subsonic and supersonic experimentation, and physical modeling to explore bleed roughness further. It was found that the phenomena can exist in the absence of bleed, that it is a function of geometry and Mach number, and that it does not appear in low subsonic flow. The inner-length scale/convective lag approach was found to be inconsistent with recent physical observation. Alternate steady models for the roughness effect disagreed with mass flux trends and the choked flow limit, and suggested that non-steady mechanisms are present. While new supersonic experiments did exhibit low-frequency plenum oscillations, high-frequency unsteadiness associated with the orifice flow scale appears to be the cause of bleed roughness. In fact, boundary-layer calculations with an oscillatory orifice flow produced the same effect in the time-averaged downstream profile for incompressible flow.

A new empirical turbulence-model is proposed which increases the eddy viscosity throughout the entire boundary-layer by a constant which is calibrated using the zero-bleed profile. Preliminary calculations agree with the experimental data. The model significantly reduces the test information required to determine roughness values for turbulence modeling, and provides prediction capability for supersonic bleed flows. The work was a major part of a thesis ⁽²⁾(abstract attached), has been discussed with local industry, and is being submitted for presentation at a national meeting.

1. Lee, J., Sloan, M.L. and Paynter, G.C., "Lag Model for Turbulent Boundary Layers Over Rough Bleed Surfaces", AIAA Journal of Propulsion and Power, Vol. 10, No. 4, 1994, pp. 562-568.

2. Laurendeau, E., "Boundary-Layer Bleed Roughness", Ph.D thesis, University of Washington, December 1995.

Abstract

Designers of supersonic inlets require knowledge of the turbulent boundary-layer developing inside the device. When necessary, bleed is applied in the region of shock-wave/boundary-layer interaction to help stabilize the shock system and reduce the risk of separation. The present study is concerned with the discovery made in 1992 of the "bleed roughness" effect, which can cause an unexpected rapid increase in the boundary-layer growth, a decrease in near-wall streamwise velocity, and an increase in the tendency of the boundary-layer to separate.

It is shown that the term bleed roughness is misleading. The bleed roughness effect has been modeled in numerical simulations of the boundary-layer and Navier-Stokes equations through modification of both algebraic and transport-type turbulence models. Wall roughness modeling using an algebraic turbulence model yields only the qualitative trends of the experimental results because the suction is much stronger than the roughness effect. The use of an auxiliary transport equation for the eddy-viscosity by Paynter yields good results numerically but is inconsistent with some of the recent physical observations of the problem.

A low-subsonic experiment was completed and analyzed along with existing data to show that the bleed roughness effect is absent in subsonic flow but present in supersonic flow for certain geometries and conditions. It is hypothesized that an unsteady flow effect from the wall boundary is the source of the phenomena. An unsteady numerical analysis was performed with a sinusoidal variation in the wall boundary-condition, leading to a reduction in the near-wall time-averaged velocity across the whole layer. A supersonic experiment reveals that unsteady effects can be present in the flow field through a Helmholtz type resonance, but that they are not responsible for the bleed roughness. It is found that the "bleed roughness" also occurs in the absence of bleed. "Bleed roughness" affects the turbulence and thus the turbulent shear stress distribution across the whole boundary-layer. A new turbulence model is advanced based on modification of the eddy viscosity throughout the whole layer. Preliminary results are in agreement with the experiments, thus providing the first prediction capability for the "bleed roughness" effect.